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LITHIUM IN THE UPPER CENTAURUS LUPUS AND LOWER CENTAURUS CRUX SUBGROUPS OF SCORPIUS–CENTAURUS

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ABSTRACT

We utilize spectroscopically derived model atmosphere parameters and the Li I λ6104 subordinate line and the λ6708 doublet to derive lithium abundances for 12 members of the Upper Centaurus Lupus and Lower Centaurus Crux subgroups of the Scorpius–Centaurus OB Association. The results indicate any intrinsic Li scatter in our 0.9–1.4 $M_\odot$ stars is limited to ∼0.15 dex, consistent with the lack of dispersion in ⩾1.0 $M_\odot$ stars in the 100 Myr Pleiades and 30–50 Myr IC 2391 and 2602 clusters. Both ab initio uncertainty estimates and the derived abundances themselves indicate that the λ6104 line yields abundances with equivalent or less scatter than is found from the λ6708 doublet as a result of lower uncertainties for the subordinate feature, a result of low sensitivity to broadening in the subordinate feature. Because non-local thermodynamic equilibrium (NLTE) corrections are less susceptible to changes in surface gravity and/or metallicity for the 6104 Å line, the subordinate Li feature is preferred for deriving lithium abundances in young Li-rich stellar association stars with $T_{\rm eff} \geqslant 5200$ K. At these temperatures, we find no difference between the Li abundances derived from the two Li I lines. For cooler stars, having temperatures at which main-sequence dwarfs show abundance patterns indicating overexcitation and overionization, the λ6104-based Li abundances are ∼0.4 dex lower than those derived from the λ6708 doublet. The trends of the abundances from each feature with $T_{\rm eff}$ suggest that this difference is due to (near)UV photoionization, which in NLTE preferentially ionizes Li atoms in the subordinate 2*p* state relative to the 2*s* resonance line state due to opacity effects. Consequently, this overionization of Li in the 2*p* state, apparently not adequately accounted for in NLTE corrections, weakens the λ6104 feature in cooler stars. Accordingly, the λ6708-based abundances may give more reliable estimates of the mean Li abundance in cool young stars. Our mean Li abundance, log N(Li) $= 3.50 \pm 0.07$ is ∼0.2 dex larger than the meteoritic value. While stellar models suggest that Li depletion of at least 0.4 dex, and possibly much larger, should have occurred in our lowest mass star(s), our Li abundances show no decline with decreasing mass indicative of such depletion.

Key words: stars: abundances – stars: late-type

1. INTRODUCTION

The identification of the lower mass members of Scorpius–Centaurus, the nearest OB Association to our Sun, has provided a rich source of nearby (within 150 pc) Sun-like pre-main-sequence (PMS) stars for understanding early stellar evolution. Sco–Cen comprises three primary subgroups: Upper Sco (US), Upper Centaurus Lupus (UCL), and Lower Centaurus Crux (LCC) with ages of ∼10 Myr (Pecaut et al. 2011), ∼15 Myr, and ∼16 Myr (Preibisch & Mamajek 2008), respectively. One of the key pieces of the puzzle of understanding young stars and their internal structure lies within understanding their lithium abundances. Since lithium is depleted during the PMS (by 0.30–1.0 dex for a 1 $M_\odot$, solar composition star; Piau & Turck-Chieze 2002), it provides a strong constraint on internal stellar structure and has provided a valuable diagnostic of youth, yet several puzzling questions remain regarding lithium depletion.

Historically, lithium has been a valuable target for much abundance work, particularly regarding open clusters. Stars with $M > 1\,M_\odot$ in the 100 Myr Pleiades cluster and in the 30–50 Myr IC 2391 and 2602 clusters evince no Li star-to-star Li dispersion above the uncertainties (Figures 3 and 7 of King et al. 2000; Figure 4 of Randich et al. 2001). One of the most vexing problems lies in the star-to-star dispersion in lithium abundances for $M \leqslant 0.8\,M_\odot$ in the Pleiades cluster (Soderblom 1993; King et al. 2010), a result at odds with standard stellar models and the lack of abundance scatter in lower mass IC 2391 and 2602 stars. In addition, Li dispersion of the size seen in the Pleiades is not apparent in lower mass stars in clusters of older ages (e.g., Hyades; Soderblom et al. 1995).

Russell (1996) examined this Pleiades dispersion by exploring lithium abundances derived from two lithium features, the strong doublet at 6708 Å (2*p*–2*s* transition) and the weaker subordinate feature at 6104 Å (3*d*–2*p* triplet transition; Grotrian diagram in Figure 3 of Carlsson et al. 1994). He found that abundances from the subordinate line were greater than those from the resonance doublet and that less scatter was observed in lithium abundances derived from equivalent widths of the 6104 Å line (±0.1 dex) when compared with those derived from the 6708 Å line (±0.2 dex). Russell (1996) suggested that a larger-scale survey of lithium in the Pleiades using the 6104 Å feature might explain the Pleiades Li dispersion as an artifact of spurious λ6708-based abundances.

Ford et al. (2002) reexamined the work of Russell (1996) using spectra of 11 late-G and early-K Pleiades and suggested that improper accounting of an Fe II blend in the 6104 Å region was likely responsible for both the decreased spread and enhanced abundances they reported. By utilizing spectral synthesis of the 6104 Å which accounted for this Fe II blending feature, the spread in abundances derived by Ford et al. (2002) was equal for both the λ6104 and λ6708 lines, indicating a

Table 1
Physical Parameters

Name	T_{eff} (K)	log g	[Fe/H]	MtVel (km s^{-1})	$\log(\frac{L}{L_\odot})$ (dex)	Mass ($M_\odot$)
MML 7	5763 ± 132	4.24 ± 0.34	-0.01 ± 0.11	2.54 ± 0.14	0.39 ± 0.06	1.3
MML 13	4984 ± 125	3.99 ± 0.54	-0.27 ± 0.10	2.53 ± 0.28	0.26 ± 0.10	1.5
MML 28	4975 ± 82	4.08 ± 0.40	-0.21 ± 0.05	2.08 ± 0.16	-0.37 ± 0.14	0.9
MML 30	5180 ± 68	4.02 ± 0.30	-0.13 ± 0.05	2.18 ± 0.12	-0.05 ± 0.09	1.1
MML 36	5198 ± 115	4.39 ± 0.29	-0.09 ± 0.09	1.96 ± 0.22	0.00 ± 0.05	1.2
MML 40	5440 ± 113	4.36 ± 0.20	-0.22 ± 0.09	3.16 ± 0.22	0.07 ± 0.08	1.2
MML 43	5580 ± 98	4.60 ± 0.28	-0.07 ± 0.08	2.59 ± 0.25	0.06 ± 0.08	1.1
MML 44	5526 ± 145	4.71 ± 0.36	-0.05 ± 0.12	2.29 ± 0.29	0.54 ± 0.10	1.5
MML 55	5228 ± 80	4.28 ± 0.24	-0.12 ± 0.07	2.50 ± 0.16	0.16 ± 0.11	1.3
MML 70	5040 ± 100	4.09 ± 0.20	-0.18 ± 0.10	2.24 ± 0.15	0.01 ± 0.10	1.2
MML 72	4950 ± 125	4.19 ± 0.44	0.06 ± 0.13	1.31 ± 0.42	0.21 ± 0.07	1.2
MML 73	5212 ± 97	4.00 ± 0.32	-0.20 ± 0.09	2.42 ± 0.19	0.21 ± 0.01	1.4

genuine abundance spread for the Pleiades. In addition, while some abundances from the subordinate line agreed with those from the 6708 doublet, there were four stars which showed clearly larger abundances from λ6104, which Ford et al. (2002) suggested might be the result of spot coverage on those stars.

Most recently, King et al. (2010) revisited lithium in the Pleiades and compared lithium abundances derived from both λ6104 and λ6708. They also found that the scatter in 6104 Å abundances persisted and was comparable to that observed in the 6708 Å results. However, contrary to Ford et al. (2002), they found little difference between abundances from the two lines; the source of these discrepant conclusions is unclear. Salient questions that remain are which line gives the most reliable Li abundances, and whether the Pleiades Li scatter is a relic of differential PMS depletion already in place by the ∼15 Myr age of our stars. While our sample's mass range limits its utility for exploring the latter, it is well suited to the former.

Recent work suggests that zero age main sequence to Hyades age dwarfs with $T_{\text{eff}} \leqslant 5200$ K show abundance anomalies which mimic the effects of overionization (Schuler et al. 2003; D'Orzai & Randich 2009). The reality of overionization in such stars can be explored using the two Li i features alone by exploiting the non-local thermodynamic equilibrium (NLTE) elements of Li i line formation at such temperatures. Due to a conspiracy of the photoionizing energies and the UV line opacity, the 6104 Å lower energy level (2p) can be depopulated relative to the 6708 Å ground state (2s) (Carlsson et al. 1994). If the extent of this effect is not accounted for in NLTE calculations, the λ6104 feature, weakened relative to the resonance line, would yield lower abundances. Might the Li-rich stars in Sco–Cen yield 6104 Å lines strong enough to measure abundances of sufficient accuracy to search for such an offset?

Motivated by these questions, we have derived lithium for a sample of UCL and LCC members of Sco–Cen. Being young (∼15 Myr), the lithium abundances in our stars are necessarily large, which decreases the uncertainty in spectral synthesis of the weaker 6104 Å lines which may affect the aforementioned studies of the Pleiades. For our mass range, the expected modest depletion factors allow us to determine abundances through spectral synthesis of both the λ6104 feature and the λ6708 doublet. We therefore derive lithium for a sample of 12 UCL and LCC members from these two lithium features. While our mass range limits the viability of answering questions regarding depletion mechanisms, we are able to robustly constrain the lithium abundances of our stars using the traditionally weaker λ6104 subordinate line as well as the λ6708 doublet. We compare the results from the two lines, analyze the differences in terms of potential NLTE effects, make recommendations for which features to use in determining lithium abundances in other young clusters and associations, and determine a mean abundance of lithium for the UCL/LCC subgroups of Sco–Cen.

2. DATA, OBSERVATIONS, AND ANALYSIS

2.1. Spectroscopic Observations and Reductions

The sample explored here is a subset of the sample of Mamajek et al. (2002), who identified members of the UCL and LCC subgroups of the Scorpius–Centaurus OB Association using X-ray, proper motions, and color–magnitude selection. Optical spectroscopy of the sample was obtained on 2002 June 14–17 with the CTIO 4 m Blanco telescope and the echelle spectrograph with a 31.6 l mm^{-1} grating and a 2048 × 2048 CCD detector. The 0.″8 slit width yielded a resolution of R ∼40,000 with a typical signal-to-noise ratio (S/N) of 60–80 per summed pixel in exposure times of ≈100–300 s. The spectra have incomplete wavelength coverage extending from approximately 5800 Å to 7800 Å, across 45 orders. The spectra have been reduced using standard routines in the echelle package of IRAF.[5] These include bias correction, flat-fielding, scattered light correction, order extraction, and wavelength calibration. We have selected stars which meet three criteria for this study: (1) their spectra have higher S/N (∼60–80), (2) they are apparently slower rotators ($v \sin i \leqslant 20$ km s^{-1}), and (3) their spectra showed no evidence of multiplicity in their cross-correlation peaks when correlated with a template solar spectrum taken with the same instrument. Further details of the velocity and multiplicity results can be found in E. J. Bubar et al. (2011, in preparation).

3. ABUNDANCE ANALYSIS AND UNCERTAINTIES

Abundances from the Li i resonance feature at 6708 Å and the 1.8 eV subordinate features at 6104 Å were derived from spectral synthesis using an updated version of the LTE analysis package MOOG (Sneden 1973). Stellar parameters were derived using excitation and ionization balance following the approach described in Bubar & King (2010) and are listed in Table 1.

[5] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

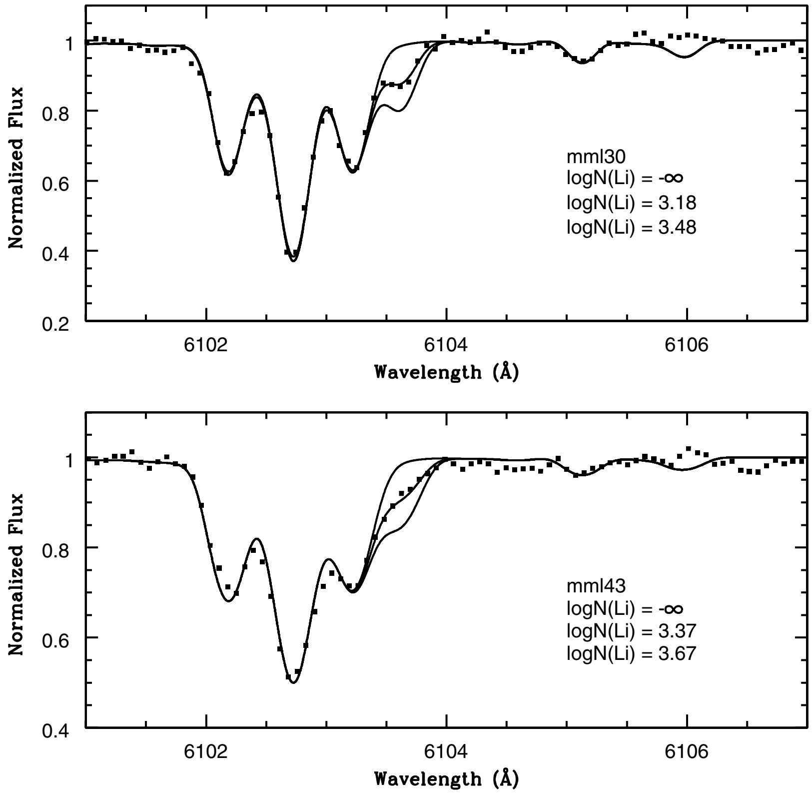

Figure 1. Sample lithium syntheses of the 6104 Å subordinate line of lithium for MML 30 (top) and MML 43 (bottom). The observed spectrum is plotted as solid squares and three syntheses are shown for each star.

Model atmospheres corresponding to these parameters were interpolated from the Kurucz ATLAS9 grids.[6] The λ6104 line list was that described and used by King et al. (2010). The λ6708 region line list was that used by King et al. (1997) updated using the CN features from Mandell et al. (2004) and additional atomic data from Kurucz[7] and VALD (Piskunov et al. 1995; Kupka et al. 1999).

For MML 28, comparison of the synthesis with the observed data in the 6708 Å region suggested a differential radial velocity shift between Li and other metal lines that could not be rectified with variations in smoothing or input abundances in a fashion that yielded acceptable fits to the 6104 Å region. The inferred differential shift of the 6708 Å feature was blueward by 0.7 km s^{-1} (−0.016 Å). Cayrel et al. (2007) found that three-dimensional NLTE modeling of the Li I feature yielded a redshifted line with respect to one-dimensional LTE results, inconsistent with the shift we observed in MML 28. Given the doublet structure of the λ6708 feature, it is possible that the magnetic intensification mechanism described by Leone (2007) could strengthen the blue component of the resonance line relative to the red component. However, our results indicate that MML 28 does not evince any line strength enhancement, relative to other stars, which should accompany such a wavelength shift relative to other stars in the sample. There is, however, observational evidence (Allende Prieto & Garcia Lopez 1998; Reddy et al. 2002; Mandell et al. 2004) that convective motions can produce Li I resonance lines with blueshifted centroids. In the 6708 Å synthesis for MML 28, we have simply shifted the synthetic Li lines by −0.016 Å, roughly two to three times the shift of the stronger Li hyperfine components applied by Mandell et al. (2004) in their line list calibrated with the Sun.

Input abundances for the initial syntheses were solar values scaled according to the [Fe/H] for each star derived by E. J. Bubar et al. (2011, in preparation). Small adjustments (a couple hundredths of a dex) within the uncertainties of E. J. Bubar et al. (2011, in preparation) were allowed if they consistently improved the fitting of blending features neighboring both the 6104 and 6708 Å Li features. Smoothing was accomplished utilizing a Gaussian with a fixed (in each wavelength region) FWHM corresponding to the instrumental resolution ($R \sim 40{,}000$) and then employing rotational broadening which consistently yielded the best fit to the line profiles in both the 6104 and 6708 Å regions. As expected, the $v \sin i$ values we determined in this fashion are (except for MML 30 and MML 73) slightly smaller than the values measured by E. J. Bubar et al. (2011, in preparation) that parameterized the total broadening (instrumental, thermal, rotational, etc.).

Representative observed spectra and syntheses (including our best-fit values) are shown in Figures 1 and 2 for the 6104 and 6708 Å regions, respectively. Comparison of our spectra with syntheses having no Li clearly and confidently indicates the presence of the blended, moderate strength λ6104 Li I feature in all but one of our stars' spectrum (MML 73). For this star, our sense is that the λ6104 is present and measurable, but two uncooperative pixels in the midst of the blended Li feature do not make this conclusion definitive (see Figure 3). Our λ6104 abundance is included in all of the statistical analyses (unless stated otherwise), but the star is denoted as an inverted triangle in the figures. The best-fit LTE Li abundances are provided in Columns 2 and 4 of Table 2.

NLTE corrections were applied to both the λ6104 and λ6708 values according to the prescription of Carlsson et al. (1994).

[6] http://kurucz.harvard.edu/grids.html
[7] http://kurucz.harvard.edu

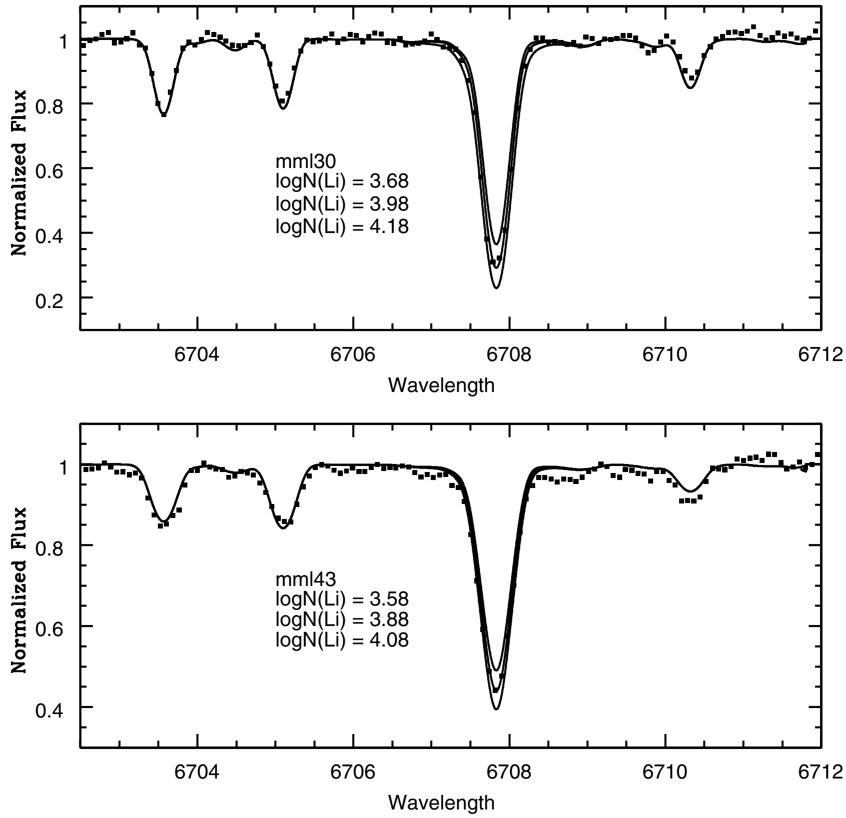

Figure 2. Sample lithium syntheses of the 6708 Å doublet of Li for MML 30 (top) and MML 43 (bottom). The observed spectrum is plotted as solid squares and three lithium syntheses are shown for each star.

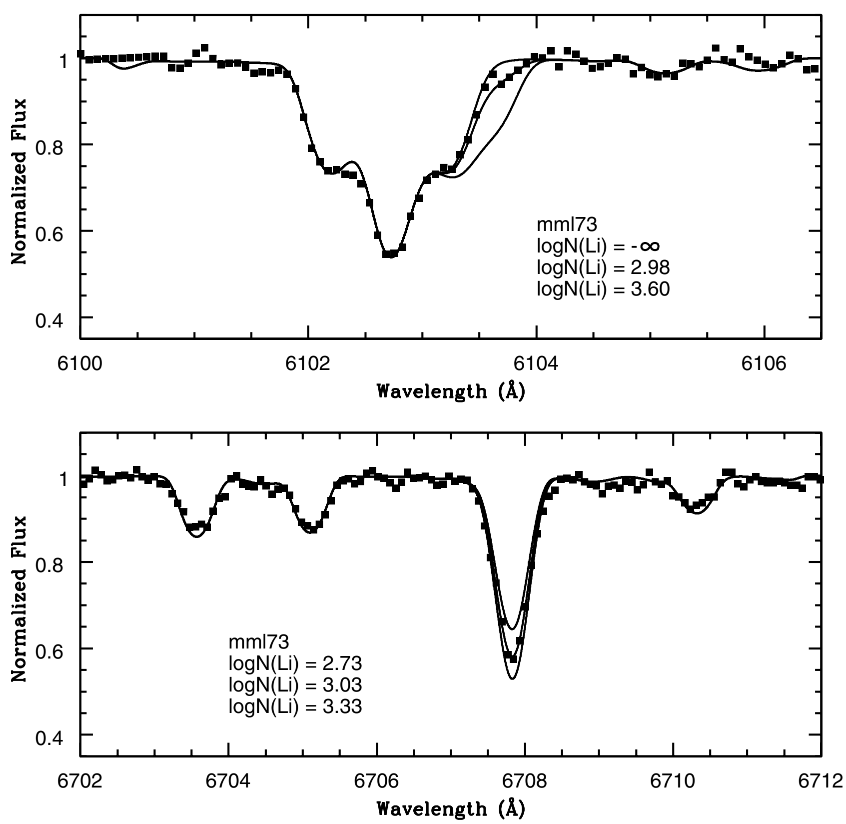

Figure 3. Sample lithium syntheses of the λ6104 line of lithium (top) and the λ6708 doublet (bottom) for MML 73. This measurable abundance of lithium from the 6104 Å feature is less definitive in this star than in the rest of our sample. The 6708 Å results, however, show the clear presence of Li in the star.

Table 2
Lithium Abundance

Name	log$N$(Li)$_{6104}$ LTE	log$N$(Li)$_{6104}$ NLTE	log$N$(Li)$_{6708}$ LTE	log$N$(Li)$_{6708}$ NLTE
MML 7	3.47	3.53 ± 0.09	4.22	3.65 ± 0.16
MML 13	3.28	3.43 ± 0.10	4.15	3.84 ± 0.21
MML 28	3.08	3.24 ± 0.08	3.93	3.56 ± 0.13
MML 30	3.18	3.31 ± 0.05	3.98	3.57 ± 0.22
MML 36	3.11	3.23 ± 0.08	4.14	3.79 ± 0.18
MML 40	3.37	3.46 ± 0.08	4.04	3.57 ± 0.15
MML 43	3.37	3.45 ± 0.08	3.88	3.43 ± 0.24
MML 44	3.24	3.32 ± 0.10	3.84	3.40 ± 0.20
MML 55	3.27	3.39 ± 0.07	3.83	3.45 ± 0.18
MML 70	3.20	3.35 ± 0.09	4.07	3.73 ± 0.16
MML 72	2.81	2.97 ± 0.10	3.59	3.29 ± 0.22
MML 73	⩽2.98	3.11 ± 0.07	3.03	2.86 ± 0.14

Interpolations within their grid of NLTE corrections provided the necessary correction to our LTE lithium abundances, based on $T_{\rm eff}$, log g, [Fe/H], and log N(Li). Three stars had absolute physical parameters which placed them outside the range of values populated by the grid. Within the adopted uncertainties of the parameters, however, the stars all fall within an acceptable extrapolation range. For MML 72, which had a supersolar metallicity of 0.06, we adopted a correction which assumed solar metallicity, justified based on the apparent insensitivity of the grid to changes in [Fe/H] (e.g., changes in metallicity of −0.71 dex and −0.14 dex are required to alter the 6104 and 6708 Å NLTE corrections by 0.01 dex at the $T_{\rm eff}$, log g, and Li abundances characterizing the star). Both MML 43 and MML 44 had surface gravities which were outside of the range covered by the Carlsson et al. (1994) grid. For these stars we assumed a surface gravity of 4.5, the maximum value in the grids. The sensitivity of the NLTE corrections to changes in the surface gravity is small: a −0.20 dex difference in gravity for both MML 43 and MML 44 results in a ⩽+0.01 dex difference in the NLTE corrections for the 6708 Å line, and log g changes of ⩾1.0 dex are needed to observe a 0.01 dex change in NLTE corrections for the 6104 Å line). This suggests that surface gravity changes have a negligible effect on the NLTE corrections, given the uncertainties. Final NLTE Li abundances are provided in Columns 3 and 5 of Table 2.

Uncertainties in the Li abundances are dominated by two general components: uncertainties in the fitting and the $T_{\rm eff}$ values (uncertainties in log g and ξ contribute negligibly). The fitting uncertainties are dominated by uncertainties in the continuum location and $v \sin i$ values. Plausible necessarily subjective estimates of allowed variations in these quantities were made and the Li abundances rederived to estimate the fitting uncertainty. These fitting uncertainties were added in quadrature with the abundance uncertainties due to the uncertainty in $T_{\rm eff}$ from E. J. Bubar et al. (2011, in preparation) to estimate the total uncertainty in our Li abundance from each of the 6104 and 6708 Å features. These are listed in Columns 3 and 5 of Table 2. We note that the uncertainties in the λ6104- and λ6708-based Li abundances due to $T_{\rm eff}$ uncertainty are correlated. When we later examine the difference between the Li abundances derived from the two wavelength regions, we account for the correlation of this component of the uncertainties in calculating the uncertainty of the difference.

4. RESULTS AND DISCUSSION

4.1. Lithium Dispersion

The 6104 Å and 6708 Å based NLTE Li abundances are plotted versus $T_{\rm eff}$ in Figure 4. In traditional open cluster work,

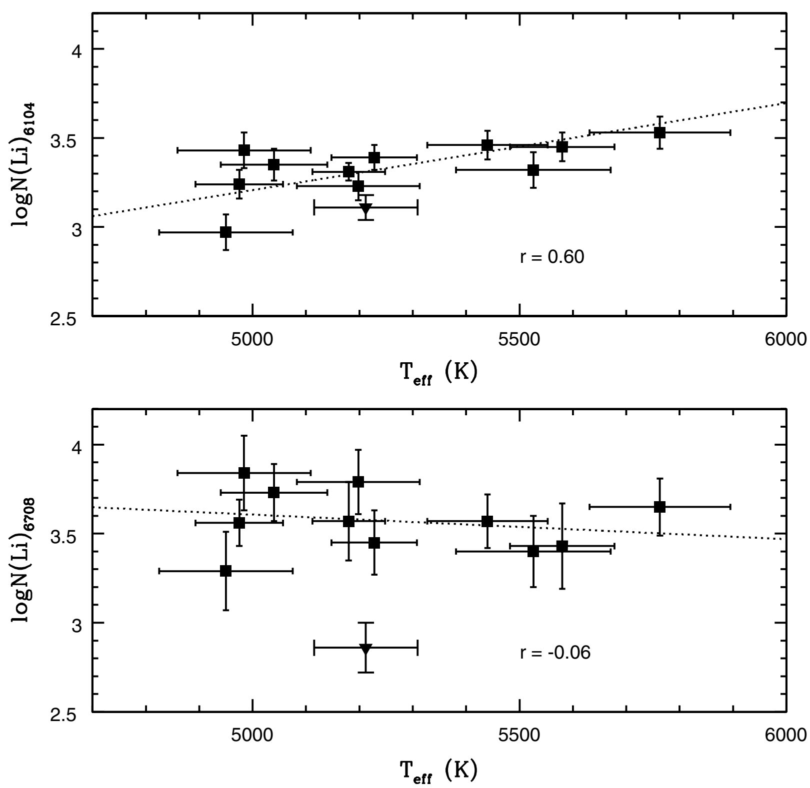

Figure 4. NLTE-corrected abundance of lithium is plotted vs. temperature for the stars based on the λ6104 subordinate feature (top) and the λ6708 resonance doublet (bottom). The least-squares fit performed in each case is shown as the dotted line, and the ordinary Pearson correlation coefficient between Li abundance in $T_{\rm eff}$ is labeled in the plots.

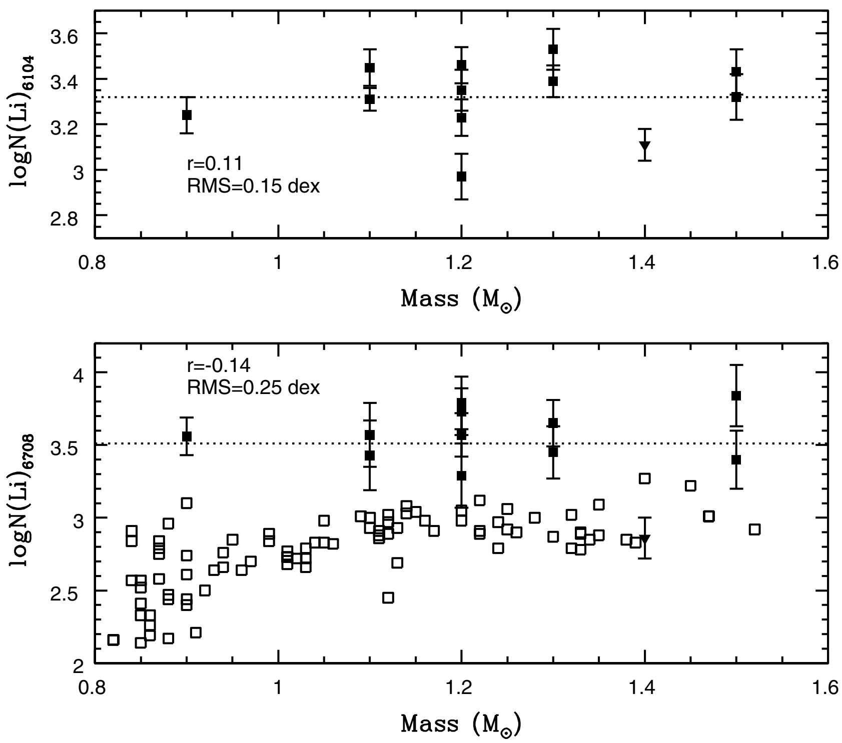

Figure 5. NLTE abundances, log $N(\mathrm{Li})_{6104}$ (top) and log $N(\mathrm{Li})_{6708}$ (bottom), are plotted vs. mass. NLTE-corrected abundances for a sample of Pleiades stars (from Soderblom 1993) are plotted for log $N(\mathrm{Li})_{6708}$ (bottom-open squares) as a comparison sample that exhibits depletion. Note that our lowest mass star clearly shows no evidence of depletion, which is contrary to stellar lithium depletion models given the age and assumed mass.

the T_{eff} coordinate serves as a monotonic mass coordinate, but this does not hold in very young star formation regions/associations such as Sco–Cen. Accordingly, we plot the NLTE Li abundances versus mass in Figure 5. We utilized bolometric luminosities from Mamajek et al. (2002) and spectroscopic effective temperatures to interpolate within the PMS grids of D'Antona & Mazzitelli (1997) in order to derive masses for our stars. It should be noted that our track-based masses may be underpredicted. According to Hillenbrand & White (2004), masses from evolutionary tracks underpredict PMS stellar masses by as much as 10%–30% when compared with dynamical masses. Such an offset could presumably account for some of the lack of observed depletion, but quantifying this is difficult with currently available models. Consequently, we proceed with the analysis making use of our derived masses.

The ordinary Pearson correlation coefficients indicate no significant variation in either Li abundance with stellar mass. A striking result is the pleasingly small scatter in the λ6104 Li I abundances compared to the λ6708-based values. The smaller scatter in the former is consistent with the smaller uncertainties we find for the former. Historically, the λ6104 line has not frequently been utilized in abundance studies due to its weakness and increased blending compared to the λ6708 resonance feature. Our results, however, suggest that the subordinate feature may produce higher quality abundances than the resonance feature in young Li-rich stars. In addition, the NLTE corrections are significantly less sensitive to changes in both metallicity and surface gravity for the 6104 line. Independent changes in log g of $\sim\pm0.20$ dex and $\sim\pm0.15$ dex in [Fe/H] yield changes of $\sim\pm0.01$ dex in the NLTE corrections for the 6708 line. A change of order 1.0 dex and 0.71 in log g and [Fe/H], respectively, is needed to see a 0.01 dex change in the NLTE correction for the 6104 line. Based on the lower scatter from the 6104 Å line and the lower sensitivity to parameter changes (log g and [Fe/H]) for NLTE corrections to the subordinate line, we conclude, similarly to Carlsson et al. (1994, see their Figure 10), that the 6104 Å feature is more well suited for obtaining lithium abundances in young, lithium-rich solar-type stars.

The rms scatter in the λ6104- and λ6708-based Li abundances about their respective means in Figure 5 (0.15 and 0.25 dex, respectively) compares favorably with the typical uncertainties (0.08 and 0.18 dex, respectively). The λ6708-based scatter is dominated by the lower abundance of MML 73; though nothing else appears remarkable or notably different about this star, the λ6708-based rms scatter of 0.17 dex found when excluding it is equivalent to that expected on the basis of the uncertainties alone. We conclude from these comparisons that any real Li dispersion—measured by the square root of the difference between the variance of the Li abundance data and the square of typical Li abundance uncertainty—in our sample of modestly rotating stars is limited to $\leqslant$0.15 dex.

The λ6708- and λ6104-based Li abundance of cool slowly rotating Pleiades with $T_{\mathrm{eff}} \leqslant 5500$ K, which characterizes most of the stars in our Sco–Cen sample, show a real dispersion of ∼0.6 dex (King et al. 2010). Comparable spreads in λ6708-based abundances are seen for $T_{\mathrm{eff}} \leqslant 5200$ K in the 50–90 Myr α Per cluster (Balachandran et al. 1996, 2011; Stauffer et al. 1999). However, mass is the relevant variable in considering PMS Li depletion, and the masses of the Pleiades that evince significant dispersion are some 0.3–0.6 $M_{\odot}$ lower in mass than the stars in our sample. Pleiades having masses comparable to those objects in our sample show no significant Li dispersion (e.g., Figure 4 of King et al. 2000). Our data therefore do not address the interesting question of whether the Pleiades and α

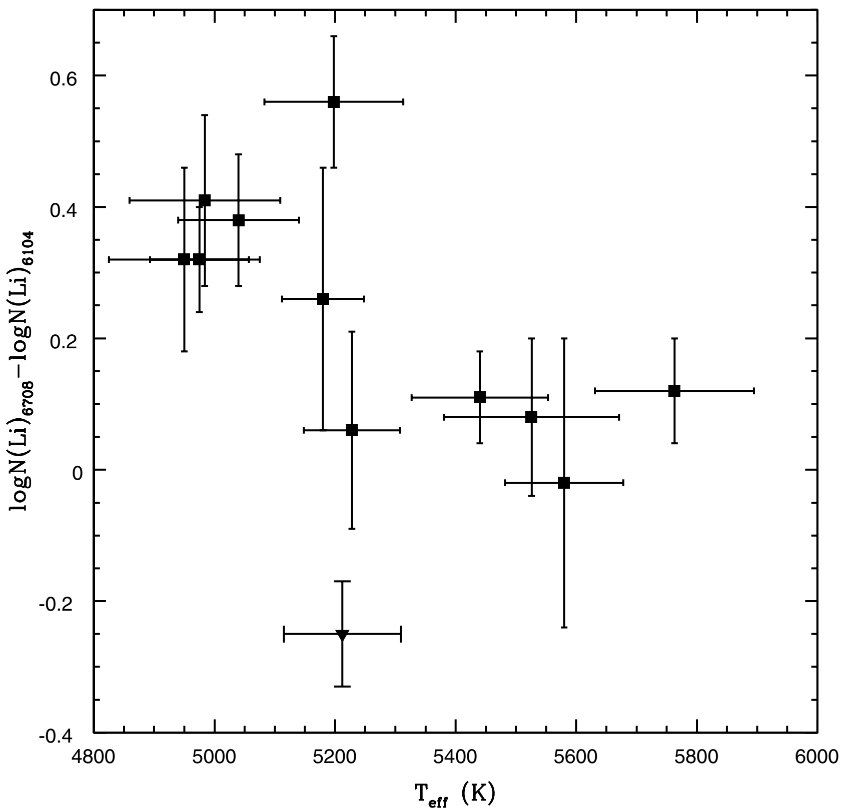

Figure 6. Difference in NLTE abundances, log $N(\mathrm{Li})_{6708}$–log $N(\mathrm{Li})_{6104}$ is plotted vs. temperature. The difference that is seen at $T_{\mathrm{eff}} \leqslant 5200$ K is due to the effects of overphotoionization on λ6104 which manifests itself by yielding lower abundances when compared with the λ6708-based abundances.

Per Li dispersion is the relic of possible differential Li depletion mechanisms having acted at the ∼15 Myr age of Sco–Cen.

4.2. *λ6104 versus λ6708*

Figure 6 shows the difference between the NLTE λ6708- and λ6104-based Li abundances versus T_{eff}. The mean difference (6708 minus 6104) is $+0.20 \pm 0.07$ (mean uncertainty) dex. The seven stars with $T_{\mathrm{eff}} \geqslant 5200$ K show no significant difference in the Li abundances derived from the two Li features, a result consistent with the abundances derived in similarly warmer Pleiades (King et al. 2010). Figure 6 indicates that the stars with statistically significant 0.3–0.5 dex abundance differences are the coolest objects in our sample.

The behavior of this difference may qualitatively fit the picture of magnetic intensification suggested by Leone (2007), where magnetic fields of 10^{-1} to 1 T can enhance the strength of strong Li i resonance features relative to weak ones. Whether such an effect would (1) hold for the λ6104 feature, (2) hold for stars of our T_{eff}, gravity, and Li abundance, and (3) "switch on" at $T_{\mathrm{eff}} \leqslant 5200$ K as we observe, requires additional calculations beyond those carried out by Leone (2007).

Recent works point to the existence of abundance patterns consistent with overexcitation/ionization in cool ($T_{\mathrm{eff}} \leqslant$ 5200 K) open cluster dwarfs (Schuler et al. 2003, 2004, 2006). However, such a mechanism (whatever its cause(s)) acting in the framework of LTE cannot explain the difference and the sense of the difference we observe in our coolest stars. Figure 2 provides an important clue to the source of the behavior in demonstrating that the λ6708–λ6104 difference is due to declining λ6104 abundances (and not increasing λ6708 abundances) with declining T_{eff}. We believe that this is a signature of relative NLTE overphotoionization at low T_{eff} acting to selectively depopulate the $2p$ level (the lower level of the λ6104 feature) relative to the $2s$ level (the lower level of the λ6708 feature), thus weakening the λ6104 line relative to the λ6708 line. Indeed, Carlsson et al. (1994) note the importance of ultraviolet photoionization as an NLTE mechanism important for Li i line formation and PMS stars exhibit greater UV emission (Findeisen & Hillenbrand 2010). A significant finding of their work is that, at low T_{eff} and high Li abundance, (near)ultraviolet metal line opacity inhibits photoionization from the Li $2s$ level, allowing photoionization from the $2p$ level to dominate.

Our results and those of King et al. (2010) indicate that the relative λ6104 versus λ6708 Li i NLTE corrections from Carlsson et al. (1994) are adequate for young Li-rich stars with $T_{\mathrm{eff}} \geqslant 5200$ K, but the λ6104 corrections are too small, perhaps by ⩾0.4 dex, at cooler T_{eff}. This suggests that while the internal uncertainties and sensitivity of NLTE corrections to stellar parameters are smaller for the λ6104 feature relative to the λ6708 feature, the absolute abundances from the λ6708 may be more reliable modulo other possible (perhaps activity-related) effects on the resonance line (King & Schuler 2004).

4.3. *Sco–Cen Lithium Abundance*

Since the λ6104 Li i abundances are likely not free of systematic errors in the NLTE corrections for the cooler stars as discussed above, our mean Li abundance estimate of log $N(\mathrm{Li}) = 3.50 \pm 0.08$ (mean uncertainty) is made from the λ6708-based NLTE results. This abundance is $\sim 2\sigma$ larger than the meteoritic value. While no mass-dependent slope to the Li data indicative of depletion is seen in Figure 5, even the most conservative PMS Li depletion models predict depletion factors of ⩾0.4 dex for 1 $M_{\odot}$ stars at an age of 15 Myr (Piau & Turck-Chieze 2002, see their Figure 4). Our results suggest the initial

Li abundance of our cooler objects might be a factor of two to three higher than observed today. On the other hand, the existence of PMS Li depletion inhibiting mechanisms remains possible (Ventura et al. 1998). Assessing whether the degree of Li depletion suffered from our Sco–Cen sample and whether our data are in agreement with PMS Li depletion models will require extending the Li-mass relation via observation and analyses of cooler, lower mass Sco–Cen members that are expected to be more prodigious depleters.

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